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Performance deterioration by weep hole in a lube oil cooler

The hydrocarbon processing industry (HPI) uses various rotating machines, such as pumps, compressors, blowers and turbines. A rotating machine is normally supplied with a lube oil system: a closed-loop system with an oil pump, an oil cooler, a filter, an oil reservoir and other devices, if necessary, as shown in **FIG. 1.**

A lube oil cooler within the lube oil system is used to eject frictional heat from bearing, jacket, seal devices and other rotation parts. A lube oil cooler is usually a small shell-and-tube type water cooler and is designed with client specifications and/or in compliance with API standard 614.[1] Generally, the Tubular Exchanger Manufacturers Association (TEMA) type for this heat exchanger is AEW or AES.

During normal operation, high alarms of lube oil temperature can be experienced because the lube oil cooler performs insufficiently during the summer season. Normally, the poor performance of a heat exchanger may be caused by one or more of the factors below. However, the poor performance of a small heat exchanger may be caused by others, including:

- High temperature of cooling water
- Low flowrate of cooling water
- Excessive fouling of shell-and-tube heat exchanger
- Tube leakage
- Thermal rating error
- Abnormal process operation.

Weep hole. A weep hole is a small hole on a pass partition plate installed inside the channel of a shell-and-tube heat exchanger. This hole is for complete drainage of the remaining liquid in the tube side, after drainage of liquid from the heat exchanger through the drain nozzle installed at the lowest point of piping. **FIG. 2** is the sectional view of a heat exchanger channel and shows weep holes.

This hole is usually a 6-mm diameter hole. Cooling water flows through the front heads (channel) and tubes of the heat exchanger, and gains heat from lube oil while a small amount of cooling water passes a weep hole without heat transfer. In most cases, this cooling water bypass is a very small amount and does not influence exchanger performance. However, this can be important in some cases. A weep hole on the pass partition plate can be the root cause of poor performance of the lube oil cooler, except in the previously mentioned causes.

Description of example case. A blower package manufacturer submitted datasheet and fabrication drawings of a lube oil cooler for review. This lube oil cooler is a TEMA AEU type with cooling water on the tube side and does not consider addition heat transfer area margin. The application of U-tubes in this example is acceptable because the cooling water for this heat exchanger is from a closed-loop cooling water system that has low fouling tendency. Weep holes in the drawing were specified as shown in **FIG. 2.** There was a 6-mm diameter hole on the pass partition plate, which divides the first and fourth tube passes. Additionally, two half holes of 6-mm diameter were specified for complete draining and venting.

The operating condition and geometrical data of the lube oil cooler are summarized in **TABLE 1.** This information comes from the blower package manufacturer.

Thermal rating and results review. For performance evaluation of the lube oil cooler, a module of an advanced thermal process design and simulation software[a] was used. No critical warning message registered on the software results. The overdesign is 0.23%, and the calculated pressure drops are less than the allowable pressure

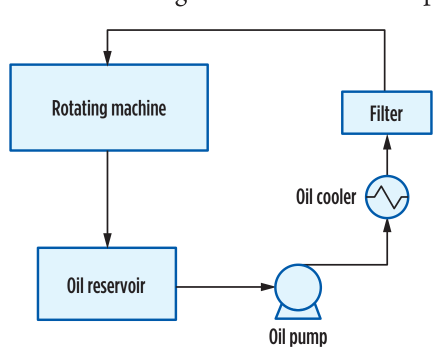

FIG. 1. Simple diagram of lube oil system in a rotating machine.

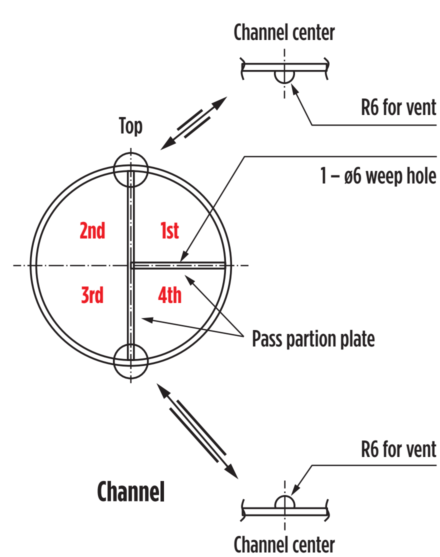

FIG. 2. Weep holes in a four-tube-pass shell-and-tube heat exchanger.

drops for both shell and tube sides, according to the software results shown in FIG. 3. In addition, this lube oil cooler was properly designed with sealing devices to avoid excessive bypass streams of the shell side.

The overall results of the heat exchanger design seemed to be acceptable, according to the rating result. However, it was noted that the consideration of bypass of cooling water was not made.

TABLE 1. Operating condition and geometrical data of lube oil cooler

	Unit	Hot side		Cold side	
Fluid name	–	Lube oil		Cooling water	
Fluid quantity	kg/hr	3,600		2,447.70	
Temperature, in/out	°C	50	40	32	39
Inlet pressure	kg^f/cm^2 g	2.472		3.5	
Pressure drop allowance	kg^f/cm^2	0.3		0.7	
Fouling resistance	m^2-hr-°C/kcal	0.0002		0.0002	
Duty	MM kcal/hr	0.0171			
Material	–	Carbon steel		Admiralty	
Design pressure	kg^f/cm^{2}g	11		8.5	
Design temperature	°C	90		80	
TEMA type	AEU	Shell ID		154.5 mm	
Tube length	3,600 mm	Number of tubes		33 Us	
Tube OD/Thickness	9.52 mm/1.24 mm	Pitch/pattern		12.693 mm / 30°	
Baffle cut	35.77%	Number of cross passes		36	
Baffle type	single-segment	Baffle orientation		perpendicular	
Baffle center space	92 mm	Impingement		None	
Shell nozzle, in/out	1.5 in./1.5 in.	Tube nozzle, in/out		1.5 in./1.5 in.	
Tube sheet thickness	30 mm	Number of shells		1 series, 1 parallel	
Baffle thickness	6 mm	Sealing parts		1 pairs seal strips, 4 x 20-mm seal rods	

TABLE 2. HTRI result

Process conditions		Hot shell side		Cold tube side	
Fluid name			Lube oil		CW
Flowrate	1,000 kg/hr		3.6		2.4477
Inlet/outlet Y	Wt. frac vap.	0	0	0	0
Inlet/outlet T	°C	50	40	32	39
Inlet P/avg.	kgf/cm2G	2.472	2.384	3	2.786
dP/Allow	kgf/cm2	0.175	0.3	0.429	1
Fouling	m2-hr-C/kcal		0.0002		0.0002
Exchanger performance					
Shell h	kcal/m^2-hr-C	418.99	Actual U	kcal/m^2-hr-C	320.19
Tube h	kcal/m^2-hr-C	5383.2	Required U	kcal/m^2-hr-C	319.47
Hot regime		Sens. Liquid	Duty	MM kcal/hr	0.0171
Cold regime		Sens. liquid	Eff. Area	m^2	7.047
EMTD	°C	7.6	Over-design	%	0.23
Shell geometry			**Baffle geometry**		
TEMA type		AEU	Baffle type		Single-seg.
Shell ID	mm	154.5	Baffle cut	% diameter	35.77
Series		1	Baffle orientation		Perpend.
Parallel		1	Central spacing	mm	92
Orientation	°	0	Crosspasses		36

Flowrate through the weep hole. What is the flowrate through the weep hole? A flowrate calculation for the orifice can be used to determine the amount of cooling water through the weep hole. The cooling water through the weep hole will be balanced with the cooling water through the tubes by the same pressure drop, as shown in FIG. 4.

The flowrate through the weep hole can be calculated with Eq. 1. If a commercial orifice software tool for the orifice is available, it can be used for calculating the flowrate through the weep hole, rather than Eq. 1.

$$Q = C_d A_o Y \sqrt{\frac{2g\Delta P}{\rho\left(1-\beta^4\right)}} \qquad (1)$$

where (TABLE 2):

	Orifice	Weep hole	Unit
Q	Flowrate through orifice	Flowrate through weep hole	m^3/sec
C_d	Discharge coefficient	Discharge coefficient	
A_o	Orifice area	Weep hole area	m^2
ΔP	Orifice pressure drop	Pressure drop through tubes	kg^f/m^2
g	Gravitational acceleration	Gravitational acceleration	9.8 m/sec^2
ρ	Density	Density	kg/m^3
β	Orifice diameter/pipe diameter	Weep hole diameter/channel diameter	
Y	Expansion coefficient	Expansion coefficient	

The parameters of Eq. 1 for the calculation of flowrate through weep hole are defined as:

Discharge coefficient (C_d) is the ratio of the actual discharge to the theoretical discharge and depends on the shape of the orifice. The weep hole is similar to a thin, sharp-edged orifice because pass partition plate thickness is small, compared to the heat exchanger inside diameter. A thin, sharp-edged orifice typically has 0.61 of discharge coefficient.

Expansion coefficient (Y) considers the difference between the discharge coefficient for compressible and incompressible flows. The expansion coefficient for liquid is 1.

Pressure drop through tubes (ΔP) in this result is 0.429 kg^f/cm^2. This pressure drop includes the pressure drops at nozzles. The pressure drops at inlet and outlet nozzles are 0.003 kg^f/cm^2 and 0.002 kg^f/

cm^2, respectively. Therefore, the net pressure drop through tubes is 0.424 kg^f/cm^2.

Channel diameter (β) is used rather than pipe diameter. Channel diameter is not the exact hydraulic upstream diameter—it can be recognized that the hydraulic upstream diameter of a weep hole is much larger than the weep hole diameter. This means that the β value is slightly affected by the hydraulic upstream diameter. Therefore, the channel diameter is enough to evaluate exchanger performance. Therefore, β will be 0.039 (6 mm divided by 154.6 mm).

Density (average) of cooling water is 991 kg/m^3.

Evaluation of heat exchanger performance with weep hole consideration. The flowrate through the weep hole can be 0.000158 m^3/sec (563 kg/hr), according to Eq. 1. Therefore, the flowrate through the tubes will be 1,884.7 kg/hr (2,447.7 kg/hr–563 kg/hr). The software[a] result of 1,884.7 kg/hr of cooling water flowrate shows that the pressure drop through the tubes is 0.269 kg^f/cm^2 with an overdesign of –30.1%. It should be noted that

HTRI — **Output Summary** — Page 1

Released to the following HTRI Member Company:

Modified MKH units

Rating - Horizontal Multipass Flow TEMA AEU Shell With Single-Segmental Baffles

No Data Check Messages.
See Runtime Message Report for Warning Messages.

Process conditions		Hot shell side		Cold tube side	
Fluid name			Lube oil		CW
Flowrate	(1,000-kg/hr)		3.6000		2.4477
Inlet/Outlet Y	(Wt. frac vap.)	0.0000	0.0000	0.0000	0.0000
Inlet/Outlet T	(Deg C)	50.00	40.00	32.00	39.00
Inlet P/Avg	(kgf/cm2G)	2.472	2.384	3.000	2.786
dP/Allow	(kgf/cm2)	0.175	0.300	0.429	1.000
Fouling	(m2-hr-C/kcal)		0.000200		0.000200

Exchanger performance					
Shell h	(kcal/m2-hr-C)	418.99	Actual U	(kcal/m2-hr-C)	320.19
Tube h	(kcal/m2-hr-C)	5383.2	Required U	(kcal/m2-hr-C)	319.47
Hot regime	(--)	Sens.Liquid	Duty	(MMkcal/hr)	0.0171
Cold regime	(--)	Sens.Liquid	Eff.area	(m2)	7.047
EMTD	(Deg C)	7.6	Over design	(%)	0.23

Shell geometry			Baffle geometry		
TEMA type	(--)	AEU	Baffle type		Single - Seg.
Shell ID	(mm)	154.50	Baffle cut	(Pct Dia.)	35.77
Series	(--)	1	Baffle orientation	(--)	Perpend.
Parallel	(--)	1	Central spacing	(mm)	92.000
Orientation	(deg)	0.00	Cross passes	(--)	36

Tube geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	33.985
Tube OD	(mm)	9.520	Shell outlet	(mm)	33.985
Length	(mm)	3600	Inlet height	(mm)	17.520
Pitch ratio	(--)	1.3333	Outlet height	(mm)	17.520
Layout	(deg)	30	Tube inlet	(mm)	33.985
Tube count	(--)	66	Tube outlet	(mm)	33.985
Tube pass	(--)	4			

Thermal resistance, %		Velocities, m/s	Min	Max	Flow fractions	
Shell	76.42				A	0.012
Tube	8.04	Tube side	1.03	1.04	B	0.604
Fouling	15.06	Cross flow	0.10	0.33	C	0.093
Metal	0.47	Longitudinal	0.13	0.24	E	0.223
					F	0.068

FIG. 3. HTRI result.

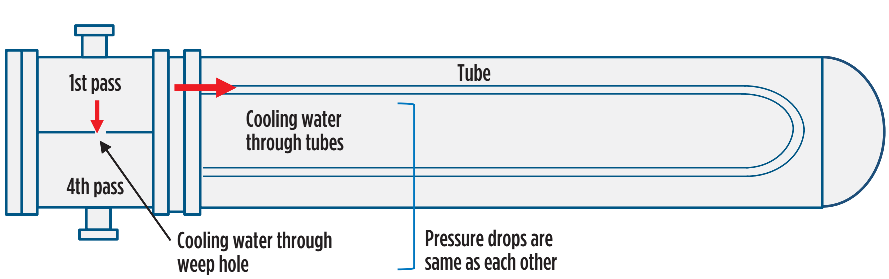

FIG. 4. Cooling water through weep hole vs. tubes.

TABLE 3. HTRI input with specifying cooling water flowrate, without specifying outlet temperature

Fluid allocation	Shell side		Tube side	
Fluid name	Lube oil		CW	
Total fluid quantity, 1,000kg/hr	3.6		1.8847	
Temperature, in/out (°C)	50/40		32/Not specified	
Vapor weight fraction, in/out	0	0	0	0
Inlet pressure, kg^f/cm^2g	2.472		3	
Pressure drop allowance, kgf/cm^2	0.3		1	
Min. fouling resistance, m^2-hr-°C/kcal	0.0002		0.0002	

TABLE 4. Exchanger performance evaluation through iterations

	1st	2nd	3rd	4th	5th
Flowrate through weep hole, kg/hr	0	563	446	471	466
Flowrate through tubes, kg/hr	2,447.70	1,884.70	2,001.70	1,976.70	1,981.70
Total pressure drop, kg^f/cm^2	0.429	0.269	0.299	0.293	0.293
MTD, °C	7.6	5.3	6	5.9	5.9
Over-design	0.23%	–30.10%	–22.10%	–23.90%	–23.90%

TABLE 5. Exchanger performance for improved design

	1st	2nd	3rd
Flowrate through weep hole, kg/hr	0	287	262
Flowrate through tubes, kg/hr	2,856.60	2568.6	2594.6
Total pressure drop, kg^f/cm^2	0.564	0.467	0.475
MTD, °C	8.4	7.9	7.9
Over-design	11.50%	4.10%	4.90%

the outlet temperature of cooling water is not specified on HTRI input as shown in **TABLE 3.** The two half weep holes can be ignored, because the calculated flowrate through half weep holes is relatively small, comparing the full diameter weep hole on the pass partition plate which divides the first and fourth tube pass.

The flowrate through the weep hole should be calculated again with the new pressure drop of tubes, 0.269 kg^f/cm^2. The flowrate through tubes will be changed to 2,001.4 kg/hr, and the pressure drop through tubes will be 0.299 kg^f/cm^2 with –22.0% of over-design. After several iterations, the mean temperature difference (MTD) will be converged, as shown in **TABLE 4.** Final performance evaluation shows that the over-design is –23.9% with a warning message showing that an "internal temperature cross exists in the exchanger" in the program result. The main reason for poor performance is due to lower MTD, rather than design. In addition, this lube oil cooler has no design margin, and potential low performance of this cooler is expected during summer season. In this example, the module of the advanced thermal process design and simulation software[a] was used for thermal rating. The software tools for heat exchanger design other than the module of the proprietary software can be used with the same concept.

Solution. To improve the lube oil cooler, performance evaluations have been performed with a smaller-diameter weep hole and more cooling water, as shown in **TABLE 5,** because both are simple to change without heat exchanger design. The weep hole size has been adjusted from 6 mm to 4 mm, which reduces the weep hole area by 56%. The cooling water flowrate has been increased from 2,447.7 kg/hr to 2,856.6 kg/hr, which is only a 409-kg/hr increase. The over-design is 4.9%, with consideration of cooling water bypass. Additionally, no warning message exists regarding temperature cross in the software result.

This evaluation and design improvements have been shared with a process engineer and a blower package manufacturer. A process engineer confirmed that the increased cooling water can be accommodated, and the blower package manufacturer agreed with reducing weep hole size.

Takeaway. In the example case, a small amount of cooling water passing a weep hole can have an effect on the performance of a lube oil cooler. The performance effect of weep hole size also depends on heat exchanger service. It is suggested that a performance evaluation that considers weep holes should be considered if a heat exchanger has two or more of the features here:

- Small cooling water flowrate in the tube side
- Operating condition causing low MTD
- Small heat exchanger
- Low heat transfer rate in the tube side.

In addition, it is recommended that an additional surface margin be added, because this kind of heat exchanger is small, and two or three tubes can provide the ample surface margin with additional low cost. HP

NOTES

[a] HTRI *Xchanger* Suite

LITERATURE CITED

[1] American Petroleum Institute, "API standard 614.1—Lubrication shaft-sealing and oil-control systems and auxiliaries," 5th Ed., April 2008.

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